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Optimization of tram face with respect to passive safety

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Abstract

An impact of a pedestrian and a tram or even an impact of two trams is a common traffic accident in towns. Hence there is an effort to develop such traffic means that minimize injuries of victims. The article deals with the optimization of placement of a previously proposed tram fender to decrease pedestrian injury risk. Further the influence of the tram fender made from different materials on passengers and tram driver injuries is investigated. The pedestrian, driver and passengers are modeled by a rigid body human model. The results analysis uses standard injury criteria based on body parts accelerations.

Keywords: biomechanical human model, passenger safety, tram driver safety, optimization of structures

1. Introduction

Virtual modeling and numerical simulations are becoming the most frequent methods used to design and optimize safety traffic systems. Not only car traffic is responsible for a number of lives. In many towns trams are often used as popular transport means. In case of a tram versus pedestrian impact, the pedestrian generally faces the consequences. However, lots of traffic participants misvalue tram technical parameters. For example the braking distance may be influenced by weather conditions. According to the police traffic report in 1999, there were 1800 tram accidents in the Czech Republic, however, only 315 of them were caused by tram drivers, cf. [11]. Therefore the analysis of pedestrian impact seems to be an important application field of biomechanical simulations. The attention is also paid to tram driver and passengers safety.

2. Human body model

Recently the biomechanical simulations come to be more and more significant. Biomechanical models of increasing complexity of a human body are developed and then applied in car industry, sport, virtual surgery, ergonomy and military.

2.1. ROBBY family

The multi-body based model ROBBY2 has been developed since 1997 for industry applications, cf. [1]. Currently the ROBBY family contains the model of a 50$^{\mathrm{th}}$ percentile man and a 5$^{\mathrm{th}}$ percentile woman. The models structure is identical, differences can be found in the geometry, mass distribution and muscles and joints characteristics. Based on a simple scaling algorithm, cf. [3], the man and woman models in the age of 6 to 55 years can be created. The ROBBY2

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model has been successfully validated for a frontal impact. An improved knee joint model suitable for a lateral impact has been implemented, cf. [2].

2.2. Injury criteria

Using rigid body models we are not able to directly recognize accident consequences on human body. The measure of injury is determined by various injury criteria based on body parts acceleration, cf. [8]. The following criteria have been defined for car passengers however, they are used also in case of the pedestrian impact [6].

With respect to the injury probability, head, thorax and knees are the most sensitive body parts. We use the general head injury criterion HIC that is computed from the acceleration $acc(t)$ of the head gravity center:

$$\text{HIC} = \max_{0 \le t_1 \le t_2 \le T} \left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} acc(t)\,\mathrm{d}t \right)^{2.5} (t_2 - t_1), \tag{1}$$

where t_2 and t_1 are two arbitrary times during the acceleration pulse. For example, the victim of an accident sustains a head injury if $\text{HIC}_{36} < 1\,000$, where the time window is $t_2 - t_1 \le 36\,ms$.

Injury of organs embedded in the thorax are judged according to 3 ms criterion, which is defined as the highest acceleration pulse lasting at least 3 ms. This pulse can not exceed 60 g.

In case of a side impact the thorax trauma index (TTI) is often used, which is related to the mean of the maximum lateral acceleration experienced by the struck side rib cage and the lower thoracic spine. For the model corresponding to the Makro 50^{th} percentile man the criterion is expressed as

$$\text{TTI(d)} = 0.5(RIB_y + T12_y), \tag{2}$$

where RIB_y represents the maximum of the absolute value of the lateral acceleration of the 4th and 8th rib on the struck side and $T12_y$ corresponds to the maximum of the absolute value of the lateral acceleration of the 12th thoracic vertebra. The serious injury of a car passenger occurs when $TTI(d)$ reaches the limit 85–90 g, hence we assume a similar value for the pedestrian impact.

One possibility how to indicate the knee injury is to monitor its lateral bending angle. According to [7] it is supposed that a knee failure occurs when the lateral bending angle reaches approximately 13°.

3. Pedestrian passive safety

The transport Research Centre has identified three basic situations of pedestrian and tram impacts, cf. [11]. Based on this research, our work has focused on the situation when a tram is arriving to the street refuge and a pedestrian suddenly enters in front of a ridden tram as depicted in fig. 1. It is essential to split the impact into two phases. During the first one the pedestrian touches the tram and is thrown away. Then the second phase follows when the victim falls to the ground and hits the surrounding infrastructure. The presented situation is focused on the primary impact only. Injuries caused by the secondary impact are not taken into account.

The simulation has been realized within the scope of the FT-TA/024 project and it has lead to shape optimization of the tram face to reduce pedestrians injuries. The collision situation has been prepared so that it corresponds to the proposal of the railway safety norms stated in [10]. The tram has moved with the initial velocity 15 km/h and it has decelerated with 0.5 g. The accident simulation has been realized with a general tram face and with a fender designed to improve the impact energy absorption, see [9]. The tram geometry and material properties have been kindly provided by ŠKODA TRANSPORTATION, s.r.o, [9]. The model represents the first part of articulated tram. The tram face is modeled as rigid.

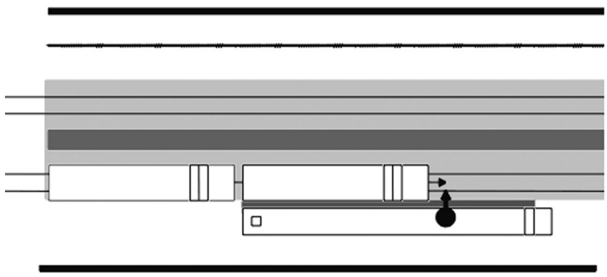

Fig. 1. Pedestrian entering the yard, scheme of the situation, taken from [11]

3.1. Adult pedestrian

The simulation presents the situation described above. The pedestrian is passing in front of an arriving tram. For this simulation the ROBBY2 model is used. The benefit of the ROBBY2 model is its ability to activate all implemented muscle elements that allow to simulate walking. Hence the impact takes place 450 ms after step out. Leg muscles have been activated according to results presented in [5] and the model has simulated normal walking with the constant velocity 1 m/s. The placements of the tram face have been analyzed with respect to injury criteria values. For comparison of the active and passive (no muscle activation) model behavior see [4].

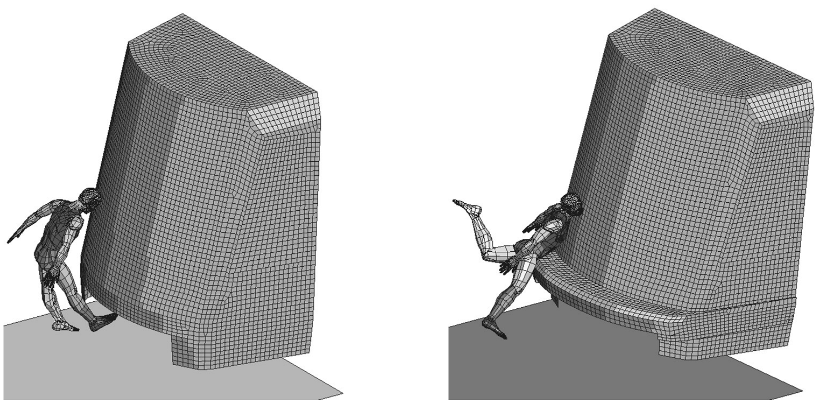

Fig. 2. The impact of the tram and the pedestrian; the tram without the fender (left) and the tram with the fender (right)

Fig. 2 shows the situation in case of the impact of the tram without the fender and with the fender. The optimization of the placement of fender is analyzed in fig. 3. The fender has been moved in the vertical direction (see different markers in the graph) and the horizontal direction (see the translation along the horizontal axis). The vertical axis represents values of injury criteria.

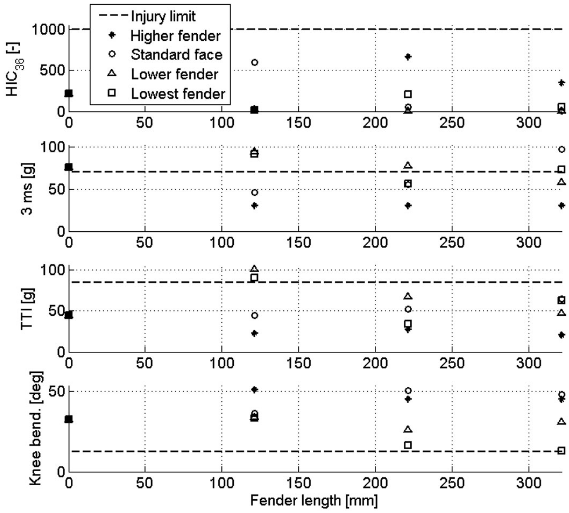

Fig. 3. Dependence of tram fender placement and values of injury criteria, adult person

It is apparent that the value of head injury criterion always lies under the limit. It is caused by the small impact velocity. The lowest fender seems to be the most responsible for the knee injuries. However, there is no situation where all the injury criteria values lie under their limits. Therefore the best seems to be the variant when the fender is placed very low and sticks out of the tram face.

3.2. Child

The analysis of child and tram impact has arose from the work presented above. The model of a six years old child has been created by the virtue of the scaling software, cf. [3]. However, there is a lack of data required to set muscle parameters and therefore the child model has been used as passive — without the muscle activities representing walking. The injuries of the child have been also analyzed based on the mentioned injury criteria. Different fender placements with respect to constructional possibilities have been again compared to the tram face without the fender. The situation is depicted in fig. 4. The optimization of placement of the fender is analyzed in fig. 5. The fender has moved again in the vertical direction (see different markers in the graph) and the horizontal direction (see the translation along the horizontal axis). The vertical axis represents values of injury criteria. The graph summarizes that more “user-friendly” tram fender with regard to the child pedestrian is that which is placed higher.

4. Driver passive safety

This section is devoted to the enhancement of driver passive safety by proposing a new tram fender and by the use of a safety belt. The fender has been connected to the tram by a translational joint to absorb more kinetic energy. The impact parameters have been set according to the standards 15227:2005 (E). The back impact has been simulated as the moving tram stroke the standing one. The velocity of the moving tram was 15 km/h.

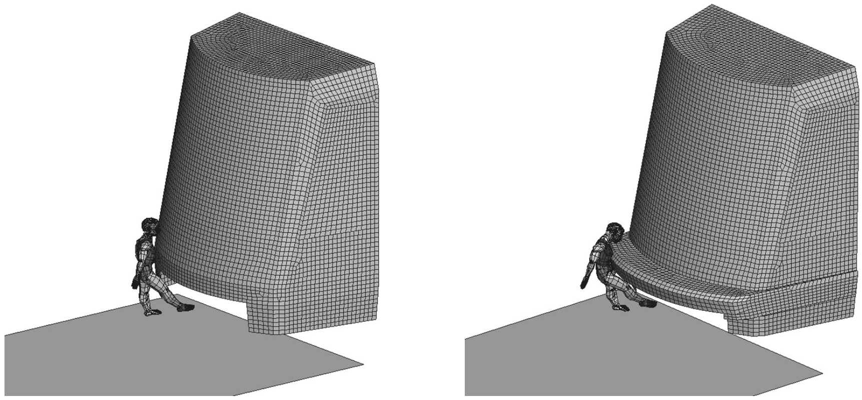

Fig. 4. The impact of the tram and the pedestrian; the tram without the fender (left) and the tram with the fender (right)

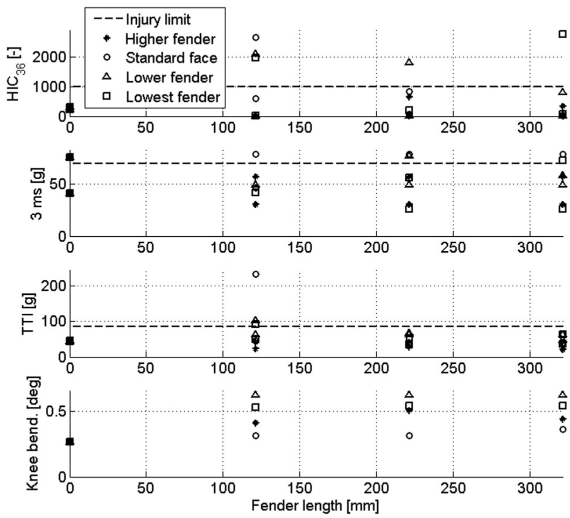

Fig. 5. Dependence of tram fender placement and values of injury criteria, child

4.1. Tram fender

The first part of this section is focused on applying a new fender made from a special material. A standard tram face has been compared to a tram face with the new fender proposed in [9]. While in case of the pedestrian impact the fender placement has been optimized, here several materials of the fender have been tested. The compared fender types were:

- standard face,
- system of pipes,
- honeycomb material.

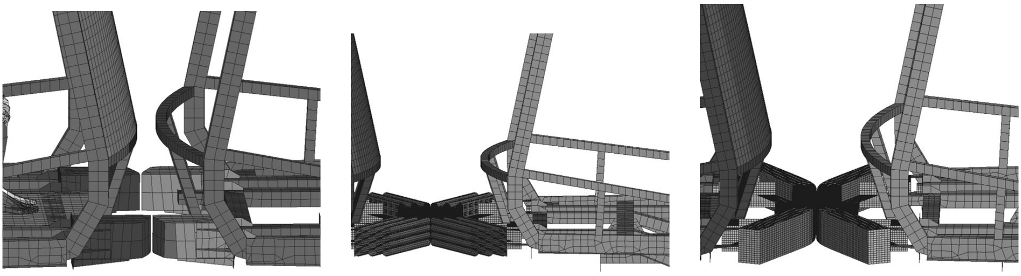

Fig. 6. Fender types; standard (left), piped (middle), honeycomb (right)

In fig. 6 all the tested variants are shown.

The evaluation of results is done again according to the injury criteria value. The comparison of the head acceleration of the driver for different fender types is shown in fig. 7 and fig. 8. The first major peak in fig. 8, left, is caused by the contact between the driver and the frontal desk. This may cause considerable injuries and hence, the driver belt is proposed and discussed later.

Based on the captured signals, the values of the head and thorax injury criteria are computed. They are summarized in tab. 1. The risk for the head injury is lower in case of the honeycomb material. On the other hand in case of the pipe fender there is lower thorax injury risk. Generally it can be summarized that both new materials absorb more energy than the standard fender.

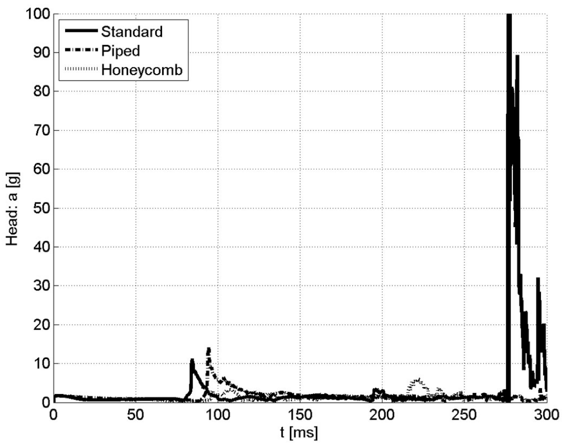

Fig. 7. Comparisson of driver head acceleration for different tram fenders

Table 1. Values of head and thorax injury criteria for different fender types

	Standard	Piped	Honeycomb
HIC_{36} [–]	217.83	0.69	0.57
3 ms [g]	26.37	7.15	8.67

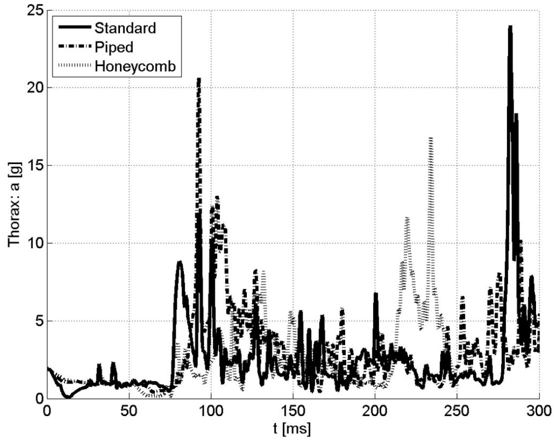

Fig. 8. Comparisson of driver thorax acceleration for different tram fenders

4.2. *Safety belt*

The second part of the section investigates the usage of a two-point safety belt for tram driver. The belt is modeled as a standard car belt, cf. [1]. The only difference is a missing retractor similarly as in planes. Fig 9 shows the whole view of the both trams including the driver and passengers.

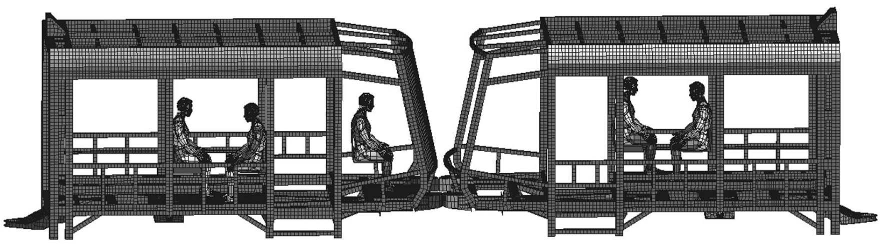

Fig. 9. Impacting trams including driver and passengers

The first numerical results (see fig. 10 and fig. 11) show worse situation caused by the use of the driver belt. However, this is caused by the rigid body based human model, because the formula for the HIC computation takes all present peaks. The second highest peak is caused by the contact between the head and thorax since because the belt limits the human body motion, the head is pushed much faster forward. This peak seems to be unrealistic since in biological reality, this contact is not rigid. Hence, the standard filter $Sae60$ is used to decrease this unreasonable peak. After this filtering, the use of the belt shows considerable improvement of the driver safety (see tab. 2).

5. Passenger passive safety

In contrast to the previous paragraph, the attention is paid to tram passengers. The same back impact of the two trams has been analyzed concerning the influence of different tram fenders

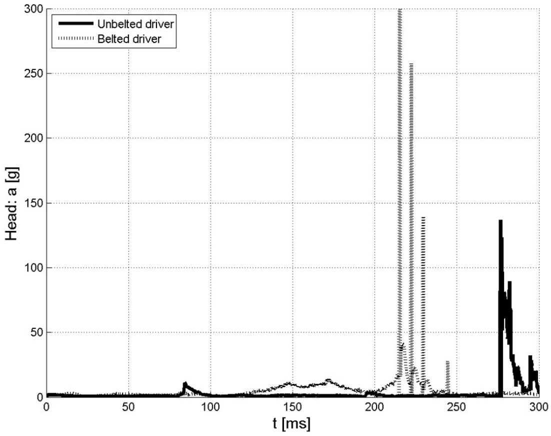

Fig. 10. Comparison of head acceleration for belted and unbelted driver

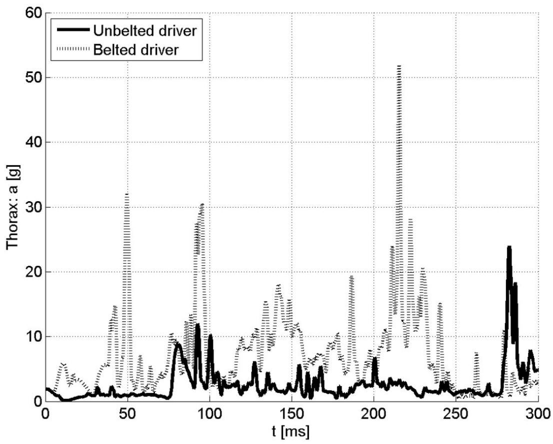

Fig. 11. Comparison of thorax acceleration for belted and unbelted driver

Table 2. Values of head and thorax injury criteria for unbelted and belted driver

	Unbelted driver	Belted driver	Belted driver, Sae60
HIC_{36} [-]	217.83	1 142	112.75
3 ms [g]	26.37	22.71	–

on passengers of the two trams. This influence has been measured by means of the acceleration of a point that was placed on the tram construction near the passenger's seat.

As expected (see fig. 12 and fig. 13), one can clearly see the improvement of the passengers' safety using the more energy absorbing fender material. Using the standard fender, there is an acceleration peak just in the beginning of the impact. This peak has been avoided using the better energy absorbing material. Due to the high noise, the curves are filtered again by the standard $Sae60$ filter.

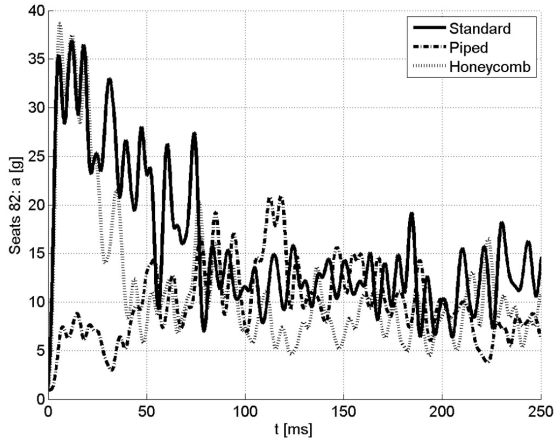

Fig. 12. Seat acceleration for bullet tram

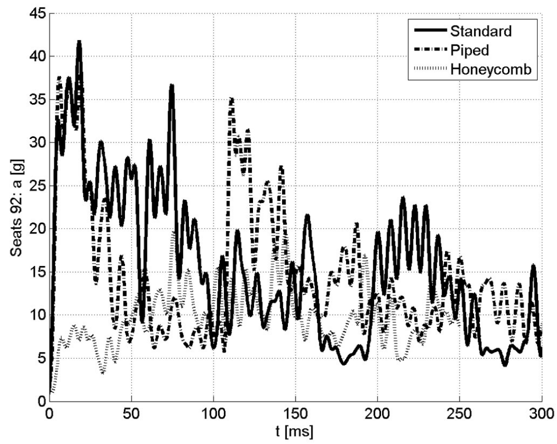

Fig. 13. Seat acceleration for target tram

6. Conclusion

Within the scope of the presented work a number of demonstrative simulations investigating the influence of tram fender on pedestrian, passenger and driver injuries have been done. The fender proposed in [9] has been used. As a pedestrian, the human body model with prescribed muscle activation has been used. For the pedestrian impact, only the position of the new proposed fender has been tested because of considerable difference of human and tram stiffnesses. For the impact of two trams also different materials has been tested. The work has lead to a new tram safety system proposal from the pedestrian, passenger and driver points of view.

Acknowledgements

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